동적 수송 요구를 고려한 컨테이너 운송 차량 대수 결정

Determination of the Fleet Size for Container Road Transportation with Dynamic Demand

양천석 [1], 고창성 [2], 정기호 [3], 신재영 [4]

[1] 대구산업정보대학 정보통신계열
[2] 경성대학교 산업공학과
[3] 경성대학교 경영정보학과
[4] 한국해양대학교 물류시스템공학과

Abstract

This study suggests an approach for determining fleet size for container road transportation with dynamic demand in Korea. With the forecasted monthly container transportation data a year, a heuristic algorithm is developed to determine the number of company-owned trucks, mandated trucks, and rented trucks in order to minimize the expected annual operating cost, which is based on the solution technologies used in the aggregate production planning and the pickup-and-delivery problem. Finally the algorithm is tested for the problem how the trucking company determines the fleet size for transporting containers.

1. Introduction

At the present time, container transportation plays a key role in the international logistics and the efforts to increase the productivity of container logistics become essential for Korean trucking companies to survive in the domestic as well as global competition. The operation and design problems related to container transportation are very complicated due to the elements such as the coverage areas, sizes of the containers, material types in the container, transportation modes, etc..

This study suggests an approach for determining fleet size for container road transportation with dynamic demand. Usually the vehicles operated by the transportation trucking companies in Korea can be classified into three types depending on the ways how their expenses occur; company-owned truck, mandated truck which is owned by outsider who entrust the company with its operation, and rented vehicle (outsourcing)[9]. From the operational point of view, the first two are essentially the same except how the drivers are paid. For the driver of company owned truck, fixed salary is paid while the driver of mandated truck is paid by the amount which is proportional to his workload. For a given set of transportation orders, the manager of the trucking company has to allocate the transportation orders to three different types of trucks taking account of the vehicle routing as well as dispatching.

Annually the trucking companies should decide how many company-owned and mandated trucks will be operated considering vehicle types and the transportation demands. With the forecasted monthly data for the volume of containers to be transported a year, a heuristic algorithm is developed to determine the number of company-owned trucks, mandated trucks, and rented trucks in order to minimize the expected annual operating cost. The idea of the algorithm is based on both the aggregate production planning (APP) and the pickup-and-delivery problem (PDP).

According to Bodin et al.[3] and Savelsbergh and Sol[16], container transportation problems belong to Pickup-and-Delivery problems. Cullen, Jarvis and Ratliff[6] performed representative research on the problems. Dumas, Desrosiers and Soumis[7] added the time windows constraint to the problem and Psaraftis[13,14] also studied the problem considering dynamic behavior. Determining truck fleet size in the presence of a common-carrier option was carried out considering the vehicle types by Ball et al.[2]. They formulated the problem and described some approximate solution strategies.

Based on Nam and Logendran[11], many researchers have also suggested a variety of analytical and heuristic approaches for APP [1,12,17] since Bowman's study[4]. Recently, APP is focused on the application in the real world problem[5,18].

2. Problem Statement

Usually volume of containers to be transported by the trucking company is fluctuated every month. When the monthly transportation data of the next year are given, the problem to determine how many vehicles for each type are required at the beginning of the year is very important problem for transportation trucking company because the number of company-owned and mandated vehicles will not change during the year. So, the trucking company should determine the number of vehicles for each vehicle types for the forthcoming year at the aim of minimizing annual operating cost.

To describe our problem, we need some assumptions; First, there exist combined vehicles only which can transport two 20' containers or one 40' container at once. Second, containers to be transported between O-D pair are both 20' and 40'. Third, we shall not be able to change the fleet size of each vehicle type over a year once the number of vehicles for each type to be operated is determined at the beginning of the year.

This problem is very similar to the APP problem. APP is performed to best utilize the human and equipment resources of a company to meet some anticipated consumer demand[11].

The difference between our problem and APP is whether the number of vehicles determined at the beginning of the year will be able to change or not. In the typical APP, the dynamic demand is satisfied through the change of the resources. On the contrary, this study assumes that the changes in the fleet sizes of company-owned and mandated vehicles will not be allowed. So the surplus monthly demands not to be covered by company-owned and mandated vehicles are all met by rented vehicles.

Cost structures for operating three types of vehicles in Korea are depicted in Figure 1. The cost of a company-owned vehicle is the sum of the fixed cost and the variable cost proportional to the transportation volume. The fixed cost includes vehicle purchasing cost, labor cost, insurance cost, etc. and is calculated as the equivalent monthly cost. The cost function of a mandated vehicle is similar to one of the company-owned vehicle, except that the fixed cost is much lower and variable unit cost is much higher than those of company-owned vehicle. Rented vehicle has only variable cost that is proportional to the shipping amount.

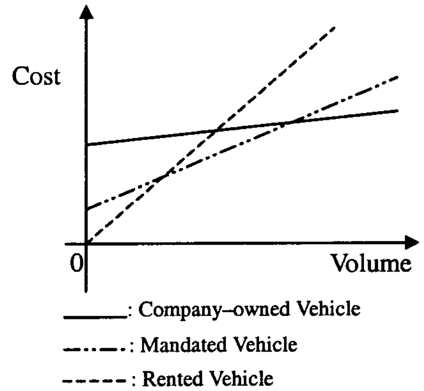

Figure 1. Cost structures for three types of vehicles.

3. Problem Model and Solution Algorithm

We present the mathematical representation to describe the framework of the problem and to derive the logic of the solution algorithm. The following notations are introduced to formulate the problem.

$I = \{ i \mid i = 1,2,3 \}$: set of vehicle types where type 1 is company - owned, type 2 is mandated, and type 3 is rented vehicle.

t : planning period, i.e. month $t = 1,2,...12$

$n(t)$: amount of containers to be transported at month

n_{it} : amount of containers to be transported by type i vehicles at period t

$N(t)$: number of vehicles required to meet $n(t)$ at period t

N_{it} : number of type i vehicles at period t

$C_i(t)$: operating cost for type i vehicle at month

F_i : fixed cost of type i vehicle

V_i : variable unit cost for containers to be transported by vehicle type i

The problem can be formulated as follows:

$$\text{Minimize} \quad TC = \sum_{t=1}^{T} \sum_{i=1}^{3} C_i(t) \tag{1}$$

$$\text{where} \quad C_i(t) = F_i N_{it} + V_i n_{it}$$

Subject to

$$\sum_{i=1}^{3} n_{it} = n(t) \qquad t = 1,2,\cdots,T \quad (2)$$

$$\sum_{i=1}^{3} N_{it} = N(t) \qquad t = 1,2,\cdots,T \quad (3)$$

$$n_{it} = f_i(n_t, C_i(t)(i=1,2,3)) \quad i \in I, t = 1,2,\cdots,T \quad (4)$$

$$N_{it} = g_i(n_t, C_i(t)(i=1,2,3)) i \in I, t = 1,2,\cdots,T \quad (5)$$

$$N_{it}, n_{it} : \text{nonnegative integer } i \in I, t = 1,2,\cdots,T \quad (6)$$

The objective function (1) is composed of annual operating costs of three types of vehicles to transport containers required to satisfy the monthly transportation demand a year. The constraints (2) represent that all the monthly demands should be shipped by the vehicles. The constraints (3) mean availability of three types of vehicles. The constraints (4) and (5) indicate that the fleet sizing and mixing of the three types of vehicles as well as the amount of containers to be shipped by each of them are related to the operating cost and transportation volume. We should notice that it is a very difficult problem to represent the two constraints explicitly since they are defined based on PDP which belongs to NP class.

Since the number of company-owned and mandated vehicles determined at the beginning of a year will not change until the end of the year, we regard the decision variables N_{1t} and N_{2t} as N_1 and N_2 regardless of t, respectively. The decision variables N_{3t} can be easily calculated as Max $\{0, N(t) - N_1 - N_2\}$.

A heuristic algorithm to solve the above model is as follows;

Step 1 (Derivation of Daily Demand)

1. Derive the average daily transportation volume for each O-D pair based on the monthly data units assuming that total working days per month are 25.
2. Set $n(t)$ as the sum of container volume for all O-D pairs at period t.

Step 2 (Solving PDP)

1. Estimate $N(t)$ required to meet $n(t)$ calculated in Step 1.1 by the Insertion Heuristic[15] which is a well-known solution algorithm in VRP (vehicle routing problem).
2. Set N_1^L, the lower bound of N_1, as Min $\{N_{1t} : t=1,\ldots,T\}$.
3. Set the upper bound of $N_1 + N_2$ as Max $\{N(t) : t=1,\ldots,T\}$
4. Sort the tours made in Step 2.1 in the decreasing order based on the total amount of containers of each tour.

Step 3 (Tabu Search)

1. Definition of Total Cost
   1. Define $TC(N_1, N_2)$ is the annual operating cost to meet $n(t)$ with N_1, N_2 and N_{3t} for a year.
   2. Assign the sorted tours obtained in Step 2.4 to the vehicles in the order of company-owned, mandated and rented vehicles.
2. Search
   1. Set an initial feasible solution (N_1, N_2) as $(N_1^L, 0)$ and calculate $TC(N_1, N_2)$.
   2. Insert the solution as the first configuration in both index list (IL) and candidate list (CL) and aspiration level (AL) is set $TC(N_1, N_2)$.
   3. Using this configuration as a seed, perform perturbations on N_1 and N_2.
   4. For two new configurations generated evaluate TC and select the configuration with the lower cost. The perturbed element of the configuration is underscored to indicate that it is tabu. If this cost is smaller than AL, a star is assigned to this configuration and admitted to CL. If there exists a tie, the two configurations are admitted to the CL. On the other hand, if the cost is either equal to or greater than AL, the configuration is simply admitted to CL without assigning a star as it does not have any potential of becoming a new local optimum as the search progresses. If the seed already has a star, then the seed receives two stars as it is a new local optimum and is admitted IL. Subsequently, the new configuration is admitted to CL.
   5. If $N_1 + N_2$ is equal to the upper bound, Go to Step 3.2.6. Otherwise, using the next available configuration from CL as the seed, perform perturbations on N_1 and N_2. Go to Step 3.2.4.
   6. The best solution obtained for TC is the smallest of all local optima evaluated so far.

4. Numerical Example

The algorithm presented above is applied to an example problem for examining its validity. The data set in the example problem is collected from a transportation trucking company in Korea.

5. Conclusion

This study suggested an approach for determining the fleet size and the vehicle mix for container road transportation with dynamic demand between O-D pairs, especially considering three types of vehicles operated. A solution algorithm was developed using APP and PDP, and Tabu search was utilized to find an optimal or a near-optimal solution. The algorithm was tested based on the trucking company in Korea.

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